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Published version

HALL, S., POLLER, B., BAILEY, C., GREGORY, S., CLARK, Richard, ROBERTS, P., TUNBRIDGE, A., PORAN, V., EVANS, C. and CROOK, B. (2018). Use of ultraviolet-fluorescence-based simulation in evaluation of personal protective equipment worn for first assessment and care of a patient with suspected high-consequence infectious disease. *Journal of Hospital Infection*, 99 (2), 218-228.

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Use of ultraviolet-fluorescence-based simulation in evaluation of personal protective equipment worn for first assessment and care of a patient with suspected high-consequence infectious disease

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ARTICLE INFO

Article history:

Received 20 November 2017

Accepted 3 January 2018

Available online 8 January 2018

Keywords:

PPE

Health care

Fluorescence visualization

Simulation

Training

Ebola



SUMMARY

Background: Variations currently exist across the UK in the choice of personal protective equipment (PPE) used by healthcare workers when caring for patients with suspected high-consequence infectious diseases (HCIDs).

Aim: To test the protection afforded to healthcare workers by current PPE ensembles during assessment of a suspected HCID case, and to provide an evidence base to justify proposal of a unified PPE ensemble for healthcare workers across the UK.

Methods: One 'basic level' (enhanced precautions) PPE ensemble and five 'suspected case' PPE ensembles were evaluated in volunteer trials using 'Violet'; an ultraviolet-fluorescence-based simulation exercise to visualize exposure/contamination events. Contamination was photographed and mapped.

Findings: There were 147 post-simulation and 31 post-doffing contamination events, from a maximum of 980, when evaluating the basic level of PPE. Therefore, this PPE ensemble did not afford adequate protection, primarily due to direct contamination of exposed areas of the skin. For the five suspected case ensembles, 1584 post-simulation contamination events were recorded, from a maximum of 5110. Twelve post-doffing contamination events were also observed (face, two events; neck, one event; forearm, one event; lower legs, eight events).

Conclusion: All suspected case PPE ensembles either had post-doffing contamination events or other significant disadvantages to their use. This identified the need to design a unified PPE ensemble and doffing procedure, incorporating the most protective PPE considered for each body area. This work has been presented to, and reviewed by, key stakeholders to decide on a proposed unified ensemble, subject to further evaluation.

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Introduction

Fundamental to the use of personal protective equipment (PPE) to protect the wearer from hazards is selection of the correct PPE and competence training. The high proportion of healthcare worker infections early in the 2013–2016 Ebola virus disease (EVD) outbreak in West Africa [1] was attributed to lack of PPE availability, protocol failure and inadequate training. This prompted healthcare providers worldwide to review their infection control procedures, including PPE choices.

In the UK during the EVD outbreak, Government expectation was that all acute care providers were to implement appropriate PPE systems for safe assessment of a febrile traveller returning from West Africa. The flexible film isolator (Trexler) system [2] in the high-level isolation unit (HLIU) of London's Royal Free Hospital (RFH) could provide safe care for up to two patients with confirmed viral haemorrhagic fever. With the possibility of exceeding the capacity of the HLIU, 'surge' centres were established in infectious disease (ID) units at RFH and at three other English hospitals – Newcastle upon Tyne Hospitals, Royal Liverpool Hospitals and Sheffield Teaching Hospitals NHS Trust (STH). PPE would be worn in place of the Trexler system in these surge centres.

In the absence of a clear evidence base, choices were made on the guidance of expert bodies such as the World Health Organization, Public Health England (PHE) and the Centers for Disease Control and Prevention, as well as considering price and availability. These factors, alongside the urgency of decision making, led to variations in PPE choices around the UK for the assessment of suspected Ebola patients.

A recent Cochrane review [3] highlighted the on-going paucity of literature supporting PPE choice, concluding that more rigorous simulation studies should be planned to address this, as well as standardized doffing procedures and training advice. During the West African EVD outbreak, the British Ministry of Defence established an ultraviolet-tracer-based simulation training package for individuals prior to deployment [4]. This proved to be an effective means of testing adherence to doffing protocols, as well as demonstrating the safety of field PPE.

As part of the review of the UK's future outbreak preparedness, the Department of Health and PHE's high-consequence infectious diseases (HCID) programme proposed the development of a national unified suspected case PPE ensemble and doffing procedure, suitable for both viral haemorrhagic fever and airborne transmissible infections.

To address the need for a unified UK PPE ensemble with demonstrable protection, supported by an effective training package, a team from the Health and Safety Executive (HSE) and the Virology and ID Departments at STH developed 'Violet', a ultraviolet-fluorescent mannequin-based simulation exercise, described in full detail elsewhere [5]. The training package differed from those used previously by the introduction of different coloured fluorochromes to represent different body fluids, thus enabling contamination to be visualized and the source of the contamination to be identified. The aim was to test the protection afforded to healthcare workers by current PPE ensembles used by five ID units during assessment of a suspected HCID case. A further aim was to provide an evidence base to justify proposal of a unified PPE ensemble for healthcare workers across the UK.

Methods

Simulation exercise

Participants

Prior to the research being undertaken, the project details were submitted to and approved by the HSE Ethics Subcommittee, which is overseen by the University of Sheffield Medical School Research Ethics Committee. Volunteers were recruited via calling notices at the participating ID units, gave informed consent and were free to withdraw at any time. Eleven volunteers (four doctors, seven nurses) completed the simulation exercise up to 10 times depending on their availability. Five volunteers (including one further doctor and nurse) acted as 'buddies' to assist with doffing. All volunteers were experienced in using the PPE ensembles adopted by their respective ID units, but if they used an ensemble from another unit, they had to undergo training to practice donning and doffing 10 times or until deemed competent by a staff trainer [5]. Limiting the number of volunteers reduced user-attributable variation.

Design and set up

The design phase of the research was undertaken at HSE's laboratory in collaboration with STH. The volunteer trials were completed in the simulation suite of the Medical Education Centre at STH. 'Violet' (Visualising Infection with Optimised Light for Education and Training) was a medical training mannequin adapted to deliver simulants of four fluorochrome-tagged body fluids during a scenario based on a doctor and nurse undertaking clinical procedures with a suspected case patient [5].

Ensembles

Each ensemble was worn over disposable scrubs for consistency.

A 'basic level' PPE ensemble (enhanced precautions as per norovirus, comprising apron, gloves, surgical mask and visor) was tested (Appendix 1) in order to confirm the belief that this PPE is insufficient to provide protection for the initial assessment and care of a suspected case patient, thereby justifying the need for a more extensive ensemble.

Five 'suspected case' PPE ensembles were also tested (Appendix 1); four from the EVD surge units and one from NHS Greater Glasgow and Clyde's ID unit in Scotland, who have had experience of managing patients with EVD and Crimean-Congo haemorrhagic fever [6,7]. These could be broadly grouped as a 'gown model' or a 'coverall model', but each had slight differences (e.g. use of hood vs surgical cap, boots vs boot covers, and different glove lengths and number of pairs). All models met the guidance of the Advisory Committee on Dangerous Pathogens [8] endorsed by PHE [9]. PPE components met their relevant material standards. All were donned and dry-doffed according to the specific protocol relevant to the ensemble (Table 1).

Procedure

Donning

Volunteers were screened using Fluorescence Interactive Video Exposure System (FIVES) [10] prior to donning PPE to

Table 1

Summary of personal protective equipment (PPE) items used in each ensemble tested

PPE type	Basic level	Royal Free Hospital	Sheffield Teaching Hospitals NHS Trust	Newcastle upon Tyne Hospitals	Royal Liverpool Hospital	Queen Elizabeth University Hospital, Glasgow
Headwear	None	Surgical cap (under mask)	Surgical cap (over mask)	Theatre hood	Hood with surgical cap underneath; tightly gathered face shape	Coverall hood
Eyewear	None	Visor	Visor	Visor	Visor	Visor
Mask	Surgical mask	FFP3	FFP3	FFP3 (over hood as no space underneath)	FFP3 mask (3M mask as structure supports face of hood)	FFP3
Body protection	None	Gown	Gown	Gown (longer length, trimmed if needed)	Coverall (back zip)	Coverall (front zip, hood)
Apron	Standard length	Long length endoscopy-grade	Long length endoscopy-grade	Long length endoscopy-grade; strings ripped and tied at neck for high fit	Long length endoscopy-grade (cut to sides and back of neck for ripping; strings looped for high fit)	Long length endoscopy-grade
Gloves	Short pair (x1)	Short first pair under gown, long second pair over gown (short third pair donned in room for dirty procedures)	Short first pair under gown, long second pair over gown, short third pair	Long first pair over gown, short second pair on top	Long purple first pair under overall, long white second pair over overall, long purple third pair	Long first pair under overall, long second pair over overall (both surgical gloves)
Glove securing	N/A	Taped second pair (lengthwise x4)	Taped second pair (lengthwise x4)	Taped first pair (3x lengthwise and around cuff)	Taped second pair (x2, front/back, lengthwise)	Not secured
Footwear	Own attire	Wellington boots	Boot covers	Wellington boots	Wellington boots (overall legs go over)	Wellington boots (under legs of suit) with boot covers over top
Underclothing	Scrubs	Scrubs	Scrubs	Scrubs	Scrubs	Scrubs
Alcohol gel in doffing ^a	No	Yes	No	Yes	Yes	Yes
Buddy PPE for doffing	No buddy	Supervises from distance	Supervises from distance	Supervises from distance	Assists: gown, cap, clogs, FFP3, visor, apron, long gloves under gown and over (not secured)	Assists: gown, boot covers, visor or combined mask/visor, surgical gloves (over gown)

^a Excludes use of gel for final hand hygiene.

ensure that there was no pre-existing contamination on their skin or scrubs from the environment, previous tests or background fluorescence. PPE was then donned under supervision by a buddy, and volunteers were screened again prior to beginning the simulation exercise.

Simulation components

The simulation exercise was designed to expose both the doctor and nurse to four bodily fluids: sweat, vomit, diarrhoea and cough fluid. Each volunteer was advised of the simulation tasks required prior to entering [5].

Post-simulation screening and qualitative evaluations

After completing the exercise, volunteers were screened front and back using FIVES to qualitatively record contamination resulting from the simulation. PPE was then removed according to protocol under the supervision of a buddy, and screening was repeated to detect any post-doffing contamination. The screening was documented by taking photographs [5] and through use of a body map of 35 discrete areas (Figure 1). The presence of contamination in an area was marked with a single dot for each colour present, representing the four different bodily fluids. The size or total number of contamination events in any area were not recorded as the presence of any contamination was classed as a significant finding, and splash contaminations were difficult to quantify.

Donning and doffing of PPE were closely observed for deviation from the guidelines. Use of checklists ensured that all volunteers followed procedures expected in the simulation, as well as noting any observed breaches or deviations (e.g. changing of gloves). The simulation was observed in real-time

from the control room, allowing optimum delivery of the body fluids to expose the participants; the simulation and doffing of PPE were also video-recorded. In addition to post-doffing contamination of participants, environmental screening using an ultraviolet lamp was undertaken to detect any cross-contamination on equipment. Although not a primary objective of the research, some buddies that physically assisted in the doffing process were screened for contamination using FIVES before and after doffing PPE following the buddying task.

During post-exercise discussions with participants, qualitative feedback was obtained regarding their opinion of the exercise, their perceptions of the protectiveness of the PPE ensembles, and practicalities of the doffing procedures.

Data analysis

The basic level PPE ensemble and four suspected case ensembles were tested in four simulation exercises. One suspected case ensemble could only be tested in three simulations as volunteers were unavailable due to clinical commitments. This resulted in a non-trained volunteer participating in the role of the nurse for one simulation; their data were excluded from the final analysis, but their participation allowed data to be captured for their doctor partner. In total, 19 suspected case simulations captured 37 volunteers. The dataset was not large enough for statistical powering or significance to be calculated.

The collected data were analysed retrospectively by reviewing body maps and corresponding photographs for each participant. Where post-doffing contamination occurred, video

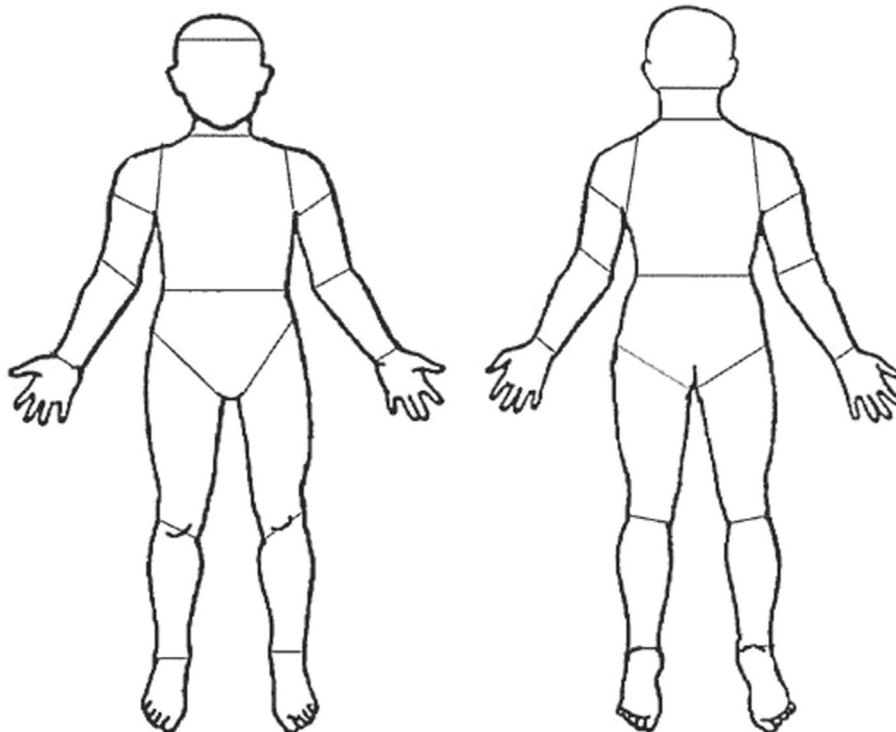


Figure 1. Body map templates used to annotate location and bodily fluid type of contamination events.

Table II

Post-simulation contamination observed on all volunteers wearing suspected case personal protective equipment used when assessing suspected high-consequence infectious diseases at Glasgow's Queen Elizabeth University Hospital and the surge units of Newcastle upon Tyne Hospitals, Royal Liverpool Hospital, London's Royal Free Hospital, and Sheffield Teaching Hospitals NHS Trust

	Head	Face	Neck	Upper body	Shoulders	Upper arms	Forearms	Hands	Lower body	Upper legs	Lower legs	Feet
Cough fluid (red)	0	12	2	19	14	47	81	28	23	19	9	3
Vomit (blue)	2	11	6	37	34	81	136	148	54	97	77	47
Sweat (orange)	0	8	5	28	11	45	125	140	38	63	14	4
Faeces (yellow)	0	1	0	3	1	6	24	49	6	17	6	3
Total	2/292	32/146	13/292	87/292	60/584	179/584	366/584	365/584	121/292	196/584	106/584	57/292

The denomination values represent the maximum number of potential contamination events.

footage was reviewed to establish the cause. The data were compared by groups of areas on the front and back of the body: head, face and neck; upper body, shoulders and upper arms; forearms and hands; and lower body, legs and feet. The number of possible contamination events was calculated for each body area by multiplying the number of volunteers by the number of sub-areas within the body region, then by the number of body fluids.

Results

Basic level PPE ensemble

In total, 147/980 post-simulation and 31 post-doffing contamination events were observed in four simulations. The cough mechanism failed to work for four volunteers, reducing the maximum number of potential contamination events. As seen in [Figure A1](#), areas of skin were exposed. Post-doffing contamination was therefore a consequence of direct skin contamination during the simulation, or via secondary contamination from PPE being transferred on to exposed skin during doffing. This confirmed that this level of PPE was not fully protective. Post-doffing contamination on the hands could be attributed to the single layer of gloves being heavily contaminated in some instances, coupled with incorrect doffing.

Suspected case PPE ensembles

Head, face and neck

In total, 47/730 contamination events occurred post-simulation ([Table II](#)) and three post-doffing ([Table III](#)). Two post-doffing contamination events were on the face. Vomit was observed on the left ear of one volunteer post-doffing and post-

simulation. Review of the footage suggested that this occurred through contact with contaminated gloves, as the volunteer was wearing a cap ensemble not a hood, and failed to don a third pair of gloves prior to changing the patient's gown once she had vomited. The second episode was vomit on the volunteer's nose. This volunteer wore glasses, and in verbal feedback described difficulty in achieving comfort and compatibility of these with the mask. Any manual adjustments of the mask could have resulted in transfer of contamination. However, when reviewing video footage the method of transfer could not be confirmed as the volunteer had unknowingly moved out of the main frame of the camera. The third event was sweat seen on the volunteer's neck post-simulation while wearing a cap ensemble. Contamination was observed to have occurred through secondary transfer from contaminated gloves and/or the stethoscope during the exercise.

Out of 13 contamination events in the neck area observed post-simulation, no contamination was seen after doffing in 12 instances. All of these ensembles included a hood. However, with the surgical cap model, the neck is left exposed, increasing the likelihood of contamination. The cough simulation malfunctioned for one test in which the volunteer was wearing a surgical cap rather than a hood. During this test, the volunteer reported feeling the jet of air on their neck; contamination was not observed but it was still considered as a significant event.

Qualitative feedback revealed no concerns relating to the use of a visor. Volunteers raised concerns about the surgical cap ensembles exposing the neck, although it allowed auscultation which was not possible when wearing a hood. However, concern was raised over the doffing procedure for the hood in one ensemble; lifting the hood over the chin with bare hands after glove removal 'felt unsafe', albeit with alcohol gel hand

Table III

Post-doffing contamination observed on all volunteers wearing suspected case personal protective equipment used when assessing suspected high-consequence infectious diseases at Glasgow's Queen Elizabeth University Hospital and the surge units of Newcastle upon Tyne Hospitals, Royal Liverpool Hospital, London's Royal Free Hospital, and Sheffield Teaching Hospitals NHS Trust

	Head	Face	Neck	Upper body	Shoulders	Upper arms	Forearms	Hands	Lower body	Upper legs	Lower legs	Feet
Cough fluid (red)	0	0	0	0	0	0	1	0	0	0	0	0
Vomit (blue)	0	2	0	0	0	0	0	0	0	0	8	0
Sweat (orange)	0	0	1	0	0	0	0	0	0	0	0	0
Faeces (yellow)	0	0	0	0	0	0	0	0	0	0	0	0
Total	0/292	2/146	1/292	0/292	0/584	0/584	1/584	0/584	0/292	0/584	8/584	0/292

The denomination values represent the maximum number of potential contamination events.

decontamination. Mask straps were positioned inconsistently, and volunteers reported confusion over the correct mask strap positioning.

Upper body, shoulders and upper arms

In total, 326/1460 contamination events occurred post-simulation (Table II), but none were seen post-doffing in this body area (Table III).

Qualitative feedback suggested that the use of a gown was more convenient for procurement and was more familiar, being used in other areas of the hospital. It also made unassisted doffing possible. The coverall 'felt protective'; however, limited availability of sizes meant that they were too large for most volunteers, resulting in discomfort, excessive material restricting movement and a potential slip risk. Coveralls also require assisted doffing, thus potentially exposing an increased number of healthcare workers. Volunteers also reported that although some modifications to the apron aided doffing, they were sometimes confusing.

Forearms and hands

In total, 731/1168 contamination events occurred post-simulation (Table II), with only one post-doffing (Table III). The single post-doffing contamination event was cough fluid seen on the back of the volunteer's right forearm, which was within centimetres of the patient's mouth while coughing. Further testing revealed that cough fluid could penetrate standard 'fluid repellent' (EN 13795 Standard Performance; AAMI Level 2) surgical gown material at close proximity, but could not penetrate a reinforced sleeve of a high-performance gown (EN 13795 High Performance; AAMI Level 3).

Donning instructions revealed a wide variation of different practices across the centres relating to glove length and fixings (longitudinal, circumferential, both or no taping using Micropore or duct tape). Qualitative feedback of the practices was that taping was preferred to no tape, and that gloves were considered to be 'more secure, less likely to slip and easier to doff' when the glove/sleeve join was taped circumferentially.

When entering the patient room wearing two layers of gloves, medical staff sometimes forgot to don a third layer before a 'dirty' procedure. This resulted in heavily contaminated gloves which could not be changed as they were secured with tape.

Lower body, legs and feet

In total, 480/1752 contamination events occurred post-simulation (Table II) and eight post-doffing (Table III). All post-doffing contamination was from vomit, and seen on the lower legs. One volunteer reported feeling the vomit dripping off their apron into their boot during the simulation. Five contamination events related to boot covers worn over shoes. Difficulties were reported in removing boot covers with scissors; therefore, most contamination events were likely to be due to this activity when contaminated gloves, scissors or contaminated boot covers touched legs, or the boot cover slipped down to expose the leg. The other two events were on each leg of one volunteer, most likely through cross-contamination from apron to gown to scrubs during doffing.

Qualitative feedback relating to boots was that a range of sizes are required, necessitating substantial storage space.

Some doffing procedures require the wearer to step out of the boots, and therefore volunteers chose sizes larger than their usual measurement to ease this process. The use of a boot jack was inconsistent, with confusion over whether it was optional or a requirement of the procedure, how it should be fixed, and where it was safe to step once out of the boot. A disadvantage of wearing boots is that they require storage in specific waste facilities pending results.

Buddying

Qualitative feedback supported having a buddy present during doffing to ensure that fatigued staff followed the correct doffing procedure by controlling the pace and providing calm reassurance. This could be done safely without any contact. Assisted doffing was considered essential for safe removal of coveralls; however, it also increases the number of healthcare workers potentially exposed. For example, evidence of PPE contamination was observed on the boot covers of one buddy after the task. This most likely occurred when crouching behind the volunteer to remove boot covers over boots. Other reported difficulties included accessing the inside of a coverall hood without touching the outside, due to the hood's elasticated gathering. Gloves were frequently observed sticking to the coverall zip shield, resulting in tearing of the glove material.

Discussion

The volunteer trial results demonstrated challenges with all of the ensembles tested; various aspects were identified for revision.

It is important to note that only two of the ensembles tested were designed to protect against an airborne pathogen; FFP3 masks were worn for splash protection only in the other models. Some masks fitted poorly, which could compromise respiratory protection and impair vision due to masks moving on the face. Some volunteers wore glasses which steamed up, showing further evidence of poorly fitted masks, and any manual adjustment would risk cross-contamination. The mask type and donning/doffing order were often determined due to perceived compatibility with other PPE (e.g. providing structure to a hood or not being able to 'fit' under a hood). Respiratory protective equipment should be worn appropriately and consistently to ensure correct use, even if being used for splash protection alone.

The open neck of cap models rather than hood models had been considered a great weakness and the results confirmed this; 2/3 post-doffing events in the head and neck area were the result of exposed skin being contaminated, with a further probable incident where air was felt but contamination not visualized due to technical failure. Furthermore, multiple contaminations on the hood were observed, which would have directly contaminated skin in its absence. High frequency of contamination of open-neck models was also observed by Zamora *et al.*, again with neck-covered models showing significantly improved protection [11].

Aprons provided an extra protective layer to the upper and lower body areas, which collectively had the third highest number of contamination events post-simulation. Endoscopy-style plastic aprons were worn for all ensembles, but there was variation in the thickness of the material. Thinner aprons were easier to doff by ripping. For thicker aprons, various methods of

cutting and tying the straps and loops allowed these to be broken to ease removal, while shortening the neck loop increased coverage of the upper body. However, some modifications to the apron caused confusion, emphasizing the need for any modifications to standard PPE to be simple and consistent. Wearing the apron higher up the body could increase exposure of the lower leg for taller wearers; therefore, it is essential that aprons worn with boots are long enough to cover the top of the boots.

Fluid penetrated gown material during one specific incident in a simulation. A UK-wide unified PPE ensemble will need to consider the level of protection afforded by PPE material (i.e. whether it should be water repellent, reinforced or waterproof). Availability of gowns and coveralls and the range of sizes stocked should also be taken into account.

For some ensembles, a colour scheme was used to distinguish between different layers of gloves, but it was not reported to provide significant advantage. Glove removal techniques were not prescribed in the doffing procedures, and were left to the experience of the medical staff, but varied widely.

Whilst the forearms and hands had the highest number of contamination events post-simulation, only one post-doffing event was observed, attributed to fabric breach as described above, rather than user error. This contrasts with other work, where the hands and forearms have been frequent sites of contamination [11–13]. However, some used two pairs of gloves, shorter lengths, no glove securing and no hand hygiene prior to examination for contamination. They also observed significant associated rates of doffing errors. During testing, a doffing buddy observed and intervened if needed, since the objective was to test the PPE itself rather than the user. All models used at least one pair of longer gloves, reaching at least mid-forearm. Use of a further 'top' pair of gloves, removed early in the doffing process, also allowed the burden of contaminated PPE to be discarded quickly, preventing further risk of cross-contamination. All ensembles required hand hygiene as a final step. In addition, alcohol gel was sometimes used on the hands between each stage of the doffing procedure. This enabled a paced doffing process, but could introduce a false sense of protection if done incorrectly.

The quality and thickness of gloves was deemed to be an important consideration as thinner gloves ripped on a number of occasions during removal. Volunteers reported that taping gloves, either circumferentially or longitudinally, reduced slipping and helped doffing; this enables glove removal as one item with the gown/coverall, removing the potential for incorrect glove doffing. In the absence of breach or self-contamination, the gloves/hands underneath should remain clean, which could contribute to the lack of contamination observed in this work. Although duct taping circumferentially was secure, other work has shown this to be detrimental, including tearing PPE [14,15]. Taping too tightly round the forearm can also prevent removal of the sleeve and attached glove over the hand. Longitudinal taping is the most likely practical solution. Consideration should be given to how gloves are removed and the number of layers necessary to minimize the risk of skin contact with heavily contaminated gloves.

The most frequent site of contamination observed post-doffing was the lower legs, and related to doffing of boot

covers. Significant contamination events related to boot cover removal have also been observed by others [12,16]. Boot covers are disposable, not size selective and require far less storage space. However, a number of disadvantages were observed. When worn without boots underneath, the covers fell down during the simulation and were awkward to walk around in due to their large size and excess material. Although they stayed in place when worn over boots and coveralls, buddy assistance was required for doffing; the tight fit made this difficult and increased the likelihood of exposure. Boots (without covers) should be available in a variety of sizes and be accompanied by clear doffing instructions. Ambiguity in the use of boot jacks led to confusion and individual interpretation. Permanent fixation to the floor is not practical for most centres, and board-fixed jacks were a trip hazard. If wearing oversized boots, use of a 'stepping out' technique must be controlled and excessive kicking avoided.

Other concerns raised during the study included:

- Some volunteers were observed pushing contaminated PPE into the bin post-doffing, which could create a potential exposure scenario, also observed by other studies [13].
- Models with many individual PPE elements and/or many donning and doffing steps required a higher level of concentration and offered more opportunities for mistakes and confusion.
- A number of the procedures included steps to modify items of PPE by cutting or tying, suggesting that the desired PPE elements are not currently readily available.

Having a buddy to instruct the process was beneficial, allowing staff to query beyond the depth of instruction cards, ensure protocol compliance or necessary intervention, and provide reassurance. To reduce the number of workers at risk of contamination, it was considered preferable that the buddy should ideally be an observer and instructor, but should not physically assist in doffing.

Although a number of post-doffing contamination events were found, it was not possible to provide significant results with the number of tests performed. However, the results obtained demonstrated a range of flaws across multiple components of the tested ensembles, providing vital information to aid development of a new ensemble. Further limitations of the study mainly concern the methodology of the exercise through the use of simulation and the use of fluorochrome qualitative markers over viral surrogates; these are discussed comprehensively elsewhere [5].

In conclusion, the results confirmed that a basic level PPE ensemble would not afford adequate protection in the simulation scenario. Direct skin contamination occurred in areas where skin was exposed and footwear was not covered or changed. In total, 147/980 contamination events were observed post-simulation and 31 remained post-doffing.

Testing of the suspected case PPE ensembles currently in use at the five ID units identified 1584/5110 post-simulation contamination events. Twelve post-doffing contamination events were observed. All PPE ensembles resulted in either post-doffing contamination or other significant disadvantages associated with their use.

Analysis of the results showed that breaches were related either to protocol failure or complications in PPE doffing, and

provided conclusive evidence of the need for improvements. After meeting with key HCID stakeholders, EVD surge units, PHE, HSE and NHS England along with lead infection prevention and control staff from the involved ID units, a UK national PPE ensemble has been proposed which will now be tested by the same methods described here and in previously reported research [5], prior to disseminating a national training programme.

Acknowledgements

The authors wish to thank all of the volunteers who gave their time to participate in this study, and the Medical Education Department of the Royal Hallamshire Hospital for their support in the use of the simulation suite facility. The PPE used was mainly provided by Sheffield Teaching Hospitals ID Unit through their funding as an Ebola surge unit, along with some PPE items from the Royal Liverpool Hospital and Newcastle

upon Tyne Hospitals. The authors also thank the staff representatives from the ID units for their time in assisting with training of volunteers and provision of PPE instructions.

Conflict of interest statement

None declared.

Funding sources

This work was funded by HSE. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy. Bozena Poller is currently funded by the Healthcare Infection Society's Graham Ayliffe Training Fellowship GATF2017/02/001; no other project costs were funded by HIS.

Appendix 1



Figure A.1. Basic level (enhanced precaution) personal protective equipment.



Figure A.2. Personal protective equipment worn when assessing a patient suspected of having a high-consequence infectious disease at London's Royal Free Hospital.



Figure A.3. Personal protective equipment worn when assessing a patient suspected of having a high-consequence infectious disease at Sheffield Teaching Hospitals NHS Trust.



Figure A.4. Personal protective equipment worn when assessing a patient suspected of having a high-consequence infectious disease at Newcastle upon Tyne Hospitals.



Figure A.5. Personal protective equipment worn when assessing a patient suspected of having a high-consequence infectious disease at Royal Liverpool Hospital.



Figure A.6. Personal protective equipment worn when assessing a patient suspected of having a high-consequence infectious disease at NHS Scotland Greater Glasgow and Clyde.

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